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INVESTIGATIONS INTO SAFE APPLICATION OF ELECTRIC POWER IN THE MINING INDUSTRY

by Prof. W.S. Kravchenko, D.Sc., USSR.

The investigations in the field of the safe application of electric power in the Mining Industry of the Soviet Union are, first of all, aimed at finding and developing of new and more effective methods for prevention of explosions, fires and injuries to mine workers by electric current.

In this connection the investigations in the field of automatic gas protection, protective switching-off for electric power circuits, the theory and practice of intrinsically safe electric systems, the modification of safe gap protection, leakage current protection, etc. are particularly promising.

AUTOMATIC GAS PROTECTION

This kind of explosion protection is based on mass application of stationary methane detectors built into machines and apparatus, and portable personal methane detectors which continuously check methane concentration at places of its probable accumulation, warn about hazardous contents of methane and switch off the electric power supply when immediate hazard of explosion arises.

The solution of this problem was achieved mainly thanks to the development of the method for methane determination with the help of low temperature catalysts (1, 2).

Two types of methane detectors have been developed:
a) the thermocatalytic type using platinum-palladium catalysts on carriers with ramified surface and b) the fast infrared type based on the well-known phenomenon of intensive absorption of infrared radiation by methane at wavelengths of 3.31 and 7.7 μ

The first type of detector is more simple and reliable in operation. It is designed for general application. The second type of detector is more complicated and expensive and is supposed to be used only in mines dangerous due to sudden coal and methane outbursts where the high speed action is desirable.

The AMT-2 stationary thermocatalytic methane-relay (Fig. 1) is intended to check methane in the outgoing ventilation airflow of a mine wall or section [3].

The sensing element of the detector consists of a platinum-palladium catalyst on a porous carrier, and a platinum resistance thermometer. The detector operation is based on flameless burning of methane on the surface of the sensing element and on the difference of the element temperature depending on the methane content. The temperature which is measured with the resistance thermometer, is proportionate to methane concentration in the mine air. The resistance thermometer is connected into the circuit of a measuring bridge to which current is supplied from the mains via a step-down transformers.

Indicators with 0-1% of methane content scale division range and 2 intermediate relays are connected into the diagonal of the detector measuring bridge; one of the relays is adjusted to send a sound warning to the controller when the methane content reaches to 0.7%, and the other - to switch off the electric power supply of the mine section and to give local warning when the methane content reaches 1%.

The possibility for carrying out the telecontrol of the methane-relay operation is provided for; for this purpose 3 signals (normal operation, 0.7% of CH_4 and 1% of CH_4) are transmitted to the controller over a pair of engaged telephone wires at increased frequencies.

The accuracy of the methane content measurement is equal to $\pm$ 0.3%; the time of the relay operation, when methane concentration near the detector increases from 0.7% to 1%, is not more than 20 sec.

The distinctive feature of the platinum-palladium thermocatalytic detector with a porous carrier is a relatively low operating temperature of the sensing element (360°C). At this temperature the detector elements do not burn out, and instrument long life is ensured.

Ageing of the sensing element has not been observed during 2 years of its uninterrupted operation in the chamber. The text of the detector at the laboratory indicates, that the presence of carbon monoxide (up to 0.5%), carbon dioxide (up to 20%), sulphur dioxide (up to 0.2%) and nitric oxides (up to 0.15%) in the mine atmosphere, an increase of relative humidity up to 98%, an increase of the ambient temperature from 10 to 30°C, as well as the presence of coal dust in concentrations up to 5 g/m^3 and a change of the speed of air flow near the detector up to 5 m/sec do not considerably affect the readings of the detector.

Only the presence of hydrogen sulphide in the mine atmosphere poisons the catalyst completely.

After removing the hydrogen sulphide, the catalytic effect of the detector sensing element restores immediately. All this testifies to the high reliability of the thermocatalytic principle of methane determination and its advantages when used under arduous mine conditions.

The low inertia infrared methane-relay is based on the principle of absorption of infrared radiation by methane. The absorption of infrared radiation by the gas being analysed is measured by means of the optical-acoustic effect [4, 5].

2 fluxes of intrared radiation from 2 radiators, interrupted by a mechanical obturator, pass through a working and a comparison chamber and enter a beam receiver (Fig. 2). In the working chamber a portion of the flux is absorbed depending on the methane concentration; as a result, the radiation flux passing through the working chamber is weak when it enters the beam receiver. The comparison chamber is hermetically sealed and does not contain absorbents, therefore the radiation flux passes through the chamber without any changes.

The resultant oscillations equal to the difference of pressure oscillations in both chambers of the beam receiver and originating due to the pulsing change of the temperature conditions, are picked up by the membrane of an electrodynamic microphone installed in the beam receiver; they are determined by methane concentration in the gas mixture under investigation.

As distinct from usual optical-acoustic instruments, the mine pick-up of low inertia methane-relay operates with a frequency of the infrared radiation flux equal to 450 c.p.s. Its single-pass working chamber has the same cross-section along the whole length and has no reflecting surfaces.

A resonance electrodynamic microphone, the resonance frequency of which is equal to the frequency of obturation and is equal to 450 c.p.s. is used in this instrument. The microphone is connected to the input of a four-stage electronic amplifier.

The output of the electronic amplifier is connected to an actuating relay. The methane-relay ensures the following:

a) de-energizing the mine section when methane concentration reaches 1.5% (the total lag from the moment of methane appearance to the moment of switching off the electric power supply by the feeder circuit-breaker is equal to 450 msec);

b) continuous checking of the methane percentage content by the indicator;

c) continuous checking of the operability of the methane-relay circuit.

The error of the instrument is equal to $\pm$ 0.5% CH_4, the weight of the methane-relay is 60 kg, its design is explosion-proof, mine type.

It can be expected that mass application of continuously operating methane detectors together with other measures will make it possible to considerably improve explosion safety in coal mines, as well as to change pneumatic power for electric power in mines which are dangerous because of sudden coal and gas outbursts, and in sections with steep beds.

Taking into account the sufficiently high accuracy and continuity of the methane content control with mass application of methane detectors, it may be possible, if necessary, to permit a slight increase of allowable methane content in the mine atmosphere and thereby to facilitate the ventilation conditions in gassy mines under highly productive systems of coal excavation.

FORESTALLING DISCONNECTION

During the last few years large-scale investigations have been carried out, aimed at reduction of the danger of explosions, fires, as well as injuries of workers by electric current in case of damage of the insulation of mine cable lines and the electrical equipment. As a result of this work, the method of "forestalling disconnection" has been proposed which is based on effecting quick power separation from the damaged portion of the cable with a speed forestalling dangerous sparking.

A case of damaging a cable by a sharp body, falling on it, is discussed below. It is known from experiments that, as a rule, the destruction of conventional power cable in an explosion chamber with the help of a body falling with the speed of 3-5 m/sec, causes methane explosion, even if the cable is disconnected automatically with the help of common-type circuit breakers.

If simultaneously quick power separation from the damaged portion is effected, the time of complete disconnection being equal to several msec, then the probability of methane ignition is considerably reduced.

High speed of the power separation (complete disconnection) of the damaged place can be insured by applying new high-speed switchgear, protective equipment and special cables.

The key connection diagram is given in Fig. 3[6].

When the insulation of cable 4 is damaged, leakage relay 2 operates, thus giving a signal to combined high-speed feeder circuit-breaker 1 and motor short-circuiting junpers 3.

At the moment of operation of circuit-breaker 1 and motor short-circuiting jumpers 3, power separation from the damaged place from the primary (transformer) and secondary (motors) power supply is effected.

The combined high-speed (disconnecting - short feeder) circuit-breaker is based on a new method of commutation [7].

This method consists in the introduction of two resistances into the circuit: one of them is variable, connected in series with the load and increasing ad infinitum toward the end of the commutation period; and the other is close to zero and connected in parallel with the load. This commutation method is carried out by an apparatus which has two mechanically interlocked contact systems: disconnecting and shorting, Fig. 3, element 1 [7].

The arc between the disconnecting contacts is used as a variable resistance, and the shorting contacts, as a parallel resistance.

In this apparatus high-speed action is achieved, on the one hand, by the application of high-speed drive and, on the other, by building it into the commutation method itself (immediately after short-circuiting, the damaged place is separated from the power supply source [8].

The motor short-circuiting jumper consists of a spring-magnetic mechanism with a permanent retaining magnet and a short-circuiting contact system.

The high speed action of the jumper is ensured by the selection of the parameters of the controlling pulse of the magnetic system and of the corresponding magnetic materials (permendur, magnico).

The employment of the rectified current of controlled circuit (three-phase voltage) and the zero-sequence current underlie the principle of operation of the high-speed leakage relay for carrying out insulation control. The high-speed action of the leakage relay is achieved by using the contactless circuit as a relay. The main elements of the circuit are semiconductors [6].

The special shielded cable is designed in such a way that at the moment of its damage a disconnection signal appears. The principal feature of the cable is a shield with contact resistance not exceeding 500 ohms.

It is known from the experiments, that the above-mentioned protective switching off system with a power insulation time of 5 msec allows reducing the probability of ignition due to the damage of the cable by a sharp falling body (when the speed of the body motion is equal to 3 - 5 msec), to 10^{-3}.

Quick disconnection of the damaged cables also considerably reduces the probability of fires near the place of damage, because with this system of switching-off even a short-circuit at the place of cable damage causes neither dangerous arc sparking nor flying-away of sparks of melted metal, nor catching fire by fuel materials located nearby.

With the protective switching-off system the sharp increase of the explosion safety of electric power supply brings hopes for the application of this method of protection in coal mines, which are particularly dangerous because of the presence of gas.

Now the task is to simplify the protective switching-off equipment and to preserve its reliability in mass production.

The theoretical investigations undertaken during the last few years in the field of intrinsic safety have contributed not only to a better understanding of the conditions of spark ignition, but also to the perfection of the methods for the evaluation and ensuring of the intrinsic safety of electric circuits in various explosive gas and vapour media.

It has been established that within the wide limits of the changes of the circuit inductance and the voltage of d. c. power supply, the ignition energy of arc and multi-puncture spark-discharges is approximately constant in case of single disconnection of the circuit [9, 18]:

$$A_{min} \approx \text{const.} \quad \ldots\ldots\ldots\ldots \quad (1)$$

and the condition of circuit spark safety is determined by the following equation [9, 18]:

$$\frac{L J^2}{2} - \frac{L J_1^2}{2} + \frac{(J - J_1)\,(U + 2 J_1 R)}{6}\tau < A_{min} \quad \ldots\ldots \quad (2)$$

When $J_1 = 0$ the condition of spark safety will be:

$$\frac{1}{2} L J^2 + \frac{1}{6} U J \tau < A_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where

- U - is the voltage of electric power supply,
- J - disconnected current,
- J_1 - current of discharge break,
- L - inductance of the circuit,
- R - resistance of the circuit,
- τ - duration of discharge.

Taking into account the anode losses which are caused by electron output work, the ignition condition will take the following form [10]:

$$\frac{1}{6}\,(U - U^x)\, J\tau + \frac{1}{2}\, L J^2 < A_{min} \quad \ldots\ldots\ldots \quad (4)$$

where

$U^x = 3\varphi \approx 10$ V

φ - potential of electron output work (arc discharge).

The approximate stability of the ignition energy and discharge duration in the circuits being analysed [10, 11, 18] makes it possible to calculate the igniting currents by the following equations:

$$J = -\frac{U\tau}{6L} + \sqrt{\left(\frac{U\tau}{6L}\right)^2 + \frac{2A_{min}}{L}}, \quad \ldots\ldots \quad (5)$$

$$J = -\frac{(U - U^x)\,\tau}{6L} + \sqrt{\left[\frac{(U - U^x)\tau}{6L}\right]^2 + \frac{2A_{min}}{L}}, \quad \ldots\ldots \quad (6)$$

These equations also permit determination from two experimental points (e.g. $L \geqslant 0.1$H, $U \leqslant 24$ U and $L \leqslant 0.001$H, $U = 50 - 100$) A_{min} and τ and then to calculate from these values the whole family of spark safety characteristics $J = J(U; L)$.

The values of igniting currents, calculated by this method have proved to be in satisfactory accord with the experiment [9, 10, 11, 18].

In inductive circuits with iron cores and shorted circuits the mathematic expression of the energy released upon disconnection (see the shaded areas in Fig. 4), which directed into the disconnection discharge, is complicated due to hysteresis and oddy currents.

However, for every inductive circuit with iron (or with a shorted circuit) it is possible to choose an ironless inductive circuit, which is equivalent to it in terms of released magnetic energy (and igniting ability).

The equivalent inductance for the hysteretic circuit (without shorted circuit) $L_{equiv.\,deg.}$ may be determined as the steepness of the iron demagnetization curve of this circuit a-c (Fig. 4, a) upon disconnection (12):

$$L_{equiv.\,deg.} = \frac{\Delta \psi}{J} \quad \ldots\ldots\ldots \quad (7),$$

where

$\Delta \psi$ is the change of flux coherence with current decrease from ... to 0.

Demagnetization curve ad (Fig. 4, b) for inductive chain with quenching circuit (with shorted turn, shunted working winding or solid iron core) is located above the static hysteresis loop, and the energy directed into the discharge (area abd, Fig. 4) decreases.

The equivalent inductance of the chain with quenching circuit is determined by the following equation [13]:

$$L_{equiv} = L_1 \left\{ 1 - 2a^2 \left[\left(\frac{\frac{L_2}{R_2}}{T} \right) - \left(\frac{\frac{L_2}{R_2}}{T} \right)^2 \left(1 - e^{\frac{-T}{\frac{L_2}{R_2}}} \right) \right] \right\} \quad \ldots\ldots\ldots \quad (8)$$

where

L_1 is the static inductance of the coil without quenching circuit, for the hysteresis chain with quenching circuit

$L_1 = L_{equiv.\,deg.}$,

L_2, R_2 are the inductance and ohmic resistance of quenching circuit respectively,

a - the coupling factor of working and quenching circuits,

T - the calculated duration of disconnection discharge; for an intrinsically safe circuit in methane-air medium $T = 150 \times 10^{-6}$ sec.

In order to simplify the calculation of equivalent induction a diagram is given in Fig. 5. Values L_1, L_2, R_2 and included in the calculation equation may be measured with the help of a special bridge [14].

Thus determined, equivalent inductance and disconnecting current can be used for the evalution of the intrinsic safety of inductance circuits with iron cores and quenching circuits from the known experimental characteristics of intrinsic safety $J = J(L; U)$ (Eqs. 5 and 6).

In inductance-capacitance circuits (the capacitor and the cable, which are connected to the discharge gap or to the inductance coil and the resistance) the spark discharge is the only form of electric discharge. The single disconnection often used during the test of inductance and active circuits, is not suitable for inductance-capacitance circuits because during a single disconnection in inductance-capacitance circuits the ignition in most cases will be determined, not by the electric power content in the system, but by the conditions of the formation of the single-puncture spark discharge. For the inductance-capacitance circuits the most severe method of sparking is intermittent sparking, during which ignition may occur owing to closing discharges. Hence it follows that in order to solve the problem of the spark safety of inductance-capacitance circuits it is necessary to know the characteristics of the igniting ability of closing discharges [15, 16, 17].

In the general case the presence of capacitance in the circuit disturbs the condition of the constancy of the igniting energy of ignition. With an increase in the condenser capacitance the igniting energy of the capacitor discharge (when the insulation is punctured) $\frac{CU_c^2}{2}$ increases.

To a first approximation the following ratio obtains at the moment close to ignition [15, 16, 17]:

$$CU_c^3 = \alpha \approx \text{const} \quad \ldots\ldots\ldots\ldots \quad (9)$$

V_c is the maximum voltage on capacitance.

Experimental diagrams $U_c = U_c(C)$ (Fig. 6), obtained for the case of igniting an explosive mixture by single-puncture discharges of the capacitor when bringing its electrodes together, approximately coincide with experimental diagrams $U_c = U_c(C)$ drawn for the case of the intermittent opening-closing of inductance circuits with capacitance, for which diagrams the value of maximum voltage on capacitance U_c during sparkless disconnection is determined from the following equation:

$$U_c = 0,5\, U + J \sqrt{\frac{L}{C}} \quad \ldots\ldots\ldots \quad (10)$$

Ignoring the first term and bearing in mind Eq. (9), we shall calculate the value of intrinsically safe current in inductance-capacitance circuits:

$$J = U_c \sqrt{\frac{C}{L}} = \alpha^{1/3} \frac{C^{1/6}}{L^{1/2}} \quad \ldots\ldots \quad (11)$$

Calculation by Eq. (11) yields satisfactory agreement with the experiment 15, 16, 17.

Experimental diagrams $U_c = U_c\,(C)$ (Fig. 6) together with the known diagrams $J = J\,(L; U)$ and $J = J\,(U)$ may be used for a preliminary evaluation of the spark safety of inductance circuits with capacitance from calculated or measured (during sparkless disconnection) maximum voltages on capacitance and capacitance values.

The limits of applying the method for the evaluation of the spark safety of inductance circuits with capacitance (including circuits with iron) from experimental characteristics $U_c = U_c\,(C)$ are yet to be determined.

The investigation of the dependence of the igniting current of disconnection discharges on the frequency (13 - 200 kc/s) and voltage (120 - 300 V) a.c. for low inductace circuits (0.08 - 2.08 mH) shows that with an increase in current frequency, the circuit inductance being constant, the igniting current increases and at a certain frequency achieves its maximum (Fig. 7[19]).

During a further increase of frequency the current igniting capability increases again (the current drops), achieves the level of direct current and at high frequencies may increase further and exceed the igniting ability of direct current.

For methane-air mixture in rise, peak and drop of the igniting current occur at considerably lower frequencies than for hydrogen-air mixture, other conditions being equal.

An increase of igniting current with frequency increase in low inductance circuits is connected with the reduction of arc duration and the decrease of discharge energy [19, 20, 21].

With a certain increase of frequency, the rate of alternating current voltage recovery begins to exceed the rate of increase of the electric strength of arc gap, and the igniting current begins falling off.

An increase in circuit inductance from 0.1 mH to 10 mH at analysed frequencies of 5-18 kc/s decreases the igniting current in hydrogen-air medium and makes it independent of frequency when inductance is more than 10 mH [21].

For inductance circuits with a capacitance connected in parallel to the discharge gap (with intermittent opening-closing) in hydrogen-air medium, an increase in 5 - 20 kc/s frequency causes a rise in the igniting current which is higher the lower the circuit inductance and the higher the capacitance[21].

When the inductance and the capacitance are connected in series, the igniting current falls off if the capacitance decreases in comparison with the resonance capacitance.

In high-frequency systems with capacitance the intrinsically safe parameters should be selected assuming series connection of the inductance and the capacitance below resonance capacitance [19].

The results of investigation into the igniting capability of high-frequency currents are of particular interest in connection with the utilization of high-frequency current in electric circuits for exploding electric detonators, as well as in communication and signalling circuits.

When applying intrinsically safe circuits in the explosive atmosphere of multicomponent mixtures of hydrocarbons of series C_nH_{2n+2}, the question of the determination of the most easily igniting concentrations in air for such mixtures arises.

On the basis of experimental data on the most dangerous concentrations for two-component mixtures (hydrocarbon-air) of series C_nH_{2n+2}, as well as for the specially prepared multicomponent mixture of the same series, it was established that the most dangerous concentrations of hydrocarbons of the alkane series (or their mixtures) in air are inversely proportional to square roots of the specific gravities γ

or molecular weights, M, of these hydrocarbons (22) :

$$\frac{V_1}{V_2} = \sqrt{\frac{\gamma_2}{\gamma_1}} = \sqrt{\frac{M_2}{M_1}} \quad \ldots\ldots \quad (12),$$

where:

V_1, γ_1, and M_1 are respectively the most dangerous volumetric concentration, the specific gravity or molecular weight of hydrocarbon (or some hydrocarbon-mixture), which are included in explosive mixture with air;

V_2, γ_2 and M_2 are corresponding values for a gas-vapour-air explosive mixture of another multicomponent composition.

Assuming for methane-air mixture V_{CH_4} = 8,5% and $\gamma_{CH_4} = 0.717$ kg/m^3, we obtain the following calculation equation for the evalution of the most dangerous concentration of any other mixture of alkane series:

$$V_c = \frac{7.2}{\sqrt{\gamma_c}} \quad \ldots\ldots\ldots\ldots \quad (13)$$

This relationship (Fig. 8) agrees well with the experimental data (circles in Fig. 8) and may be used for practical calculations.

It has also been established [22] that igniting current decrease as the specific gravity of the explosive component of the multicomponent mixture of series C_nH_{2n+2} increases. Therefore, when solving the question of the most dangerous composition of explosive mixture circuit, it is necessary to aim at the heaviest mixture from among the practicable combinations or at a two-component mixture (Hydrocarbon-air) which is equivalent to it.

When experimentally determining igniting current arising during the break of the electric circuit in the explosion chamber or when determining the igniting voltages appearing during capacitance discharges, the statistical nature of spark ignition becomes apparent. The instability of spark ignition is caused by the variety and instability of the affecting factors, which are caused by both the equipment which does not permit ensuring, from experiment to experiment, accurate reproduction of the same sparking conditions on the contacts, and by the physical processes of electric discharge and development of flame nucleus.

Under these conditions, in spite of the imperfection of the equipment, the application of statistical methods for processing experimental data permits revealing the actual qualitative and quantitative characteristics of phenomena under study among the scattered and unstable data.

During the spark ignition experiments it was established that the ignition probability, P, decreases (other conditions being equal) exponentially depending on disconnecting current decrease or decrease of the voltage on discharged capacitance [18, 23]:

$$P = aJ^n \quad \ldots\ldots\ldots\ldots \quad (14)$$

where:

a, n are the constants taken from the experiment (we managed to observe these dependences within the limits of $P = 10^{-1}$ to 10^{-7}).

Under the conditions of actual experiment the discovered statistical regularities permit us to do the following: a) reduce the igniting currents of igniting maximum voltages on capacitance, or igniting powers energies, etc., which were determined from experiment, to conditions of equiprobable ignition; b) using the above-mentioned experimental data, plot quantitative dependences characterizing the igniting abilities of electric circuits under the actual conditions of experiment (between current and inductance, between voltage and capacitance, etc.); c) using the known safety factor, give a quantitative evaluation of the expected decrease or increase of ignition probability in case of a change in a particular parameter of the electric circuit.

The experimental equipment, i.e. explosion chambers, which has been developed for the statistical evaluation of the spark safety of electric circuits, makes possible quick accumulation of a great number of experimental data and using them for determination of ignition probability from electric sparking in the circuit being analysed.

The high-speed action of the explosion chamber (Fig. 9) developed by the A. A. Skochinsky Institute of Mining [24], is achieved owing to the automation of washing and filling of the chamber with explosive mixture and the automation of the calculation of the number of explosions and failures.

The sparking in the chamber is due to the intermittent closing-opening of contacts (small saw and pivot for testing the circuits with capacitance) and to the single disconnection of the circuit when the wire comes off the pivot (for testing inductive circuits).

The explosion chamber of UND Mak NII is noted for the high stability of sparking which is ensured by the application of a special spark-forming mechanism(Fig. 10). Disconnection discharges occur upon break of the wire each time at a new place, and thanks to this the burning of contacts and their blunting are excluded.

The break of contacts takes place in the small glass flask, through which the explosive mixture is blown. The chamber is automated and provided with automatic counters of explosions and failures. The chamber is designed for testing low-inductance circuits.

The application of intrinsically safe electric circuits is of great practical interest not only for gas coal mines, but still more for enterprises of the Chemical, Oil and Gas Industries. In connection with this, the important problem in the field of spark safety is the development of the classification of explosive gas-vapour-air mixtures according to the hazard of ignition from electric discharges. It is also necessary that a further development of theory, the perfection of evaluation methods and search for new methods for ensuring spark safety of electric circuits in various explosive mediums should be carried out.

EXPLOSION-PROOF ENCLOSURES

Accidental arcing inside an explosion-proof enclosure creates a number of additional hazards: a) ejection of incandescent metal particles through flange clearances; b) destruction of shells by increased pressures; c) excessive heating of the enclosure walls.

MakNII[25] has investigated the influence of a number of factors on the value of flanged clearance, namely: the configuration of flanged joint; the free volume of the shell; the distance between electrodes and flanges; the arc current; the pressure developing in the shell; the fuel content in the mixutre; the material of electrodes and flanges; the excessive initial pressure of the explosive mixture; the elastic deformation of flanges occurring under the pressure of explosion.

The influence of small volumes and blocking walls (which are installed before the flange clearance) on the value of safety clearance for highly dangerous gases (hydrogen, acetylene [26] has been investigated. It has turned out that the presence of the wall (which blocks the release of gases) in front of the flange clearance increases the probability of explosion transfer from shells and affects their protective properties.

At the same time, a conserable reduction of inner void volume in the shells from 2.5 lit. to 0.1 - 0.3 lit decreases the pressure in the shells and loads to an increase in the safety clearance.

The latest results open up the possibility for creating explosion-tight shells with small free columé for dangerous gases.

The brief review of the latest results of the work in the field of safety application of electric power in coal mines, which is given in the present paper, does not exhaust all achievements of the USSR in this field.

The author hopes that this brief information will help others use the contribution of the Soviet Union in the cause of miners' safety.

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FIGURES

Fig. 1: Connection diagram of mine thermocatalytic analyser of methane ANT-2 (1, left), signalling instruments (2) feeder circuit-breaker of mine section (3) and signalling system of controller (4).

Fig. 2: Block diagram of infrared low-inertia mine methane-relay:
1 - infrared radiation source; 2 - obturator; 3 - obturator motor; 4 - working chamber; 5 - comparison chamber; 6 - beam receiver; 7 - microphone; 8 - electrone amplifier; 0 - power supply unit; 10 - actuating unit

Fig. 3: Circuit diagram of connection of forestalling switching-off apparatus into electric power supply system of mine section:
1 - combined high-speed feeder circuit-breaker; 2 - high-speed leakage relay; 3 - motor short-circuiting jumpers; 4 - special shielded cable; 5 - magnetic starters

Fig. 4: Dependence of flux coherence ψ of coil with iron: (a) and shorted circuit, (b) upon current J during disconnetion

Fig. 5: Diagram for calculation of equivalent inductance of coil with iron core and shorted circuit

Fig. 6: Dependence of signiting voltage, V_c, on capacitance, upon circuit capacitance, C, for methane-air (upper curve) and hydrogen-air (lower curve); mediums according to experimental data of various authors [11]:
■ - puncture discharges upon wire shorting;
□ - intermittent sparking (K. Müller);
x - intermittent sparking - amplitude values of alternating (5-15 kc/s) voltage across contacts (V. S. Kravchenko, Sing Yu-chî);
•▲ - discharges when the copper contacts come together;
•Δ - same when the platinum contacts come together (B. A. Petrenko), Ignition probability $\sim 10^{-2}$

Fig. 7: Dependence of igniting current upon frequency at constant inductance. Ignition probability - 10^{-3}

Fig. 8: Dependence of most readily igniting concentrations, v (2), upper (1) and lower (3) explosion limits of saturated hydrocarbons C_nH_{2n+2} and their mixtures on specific gravity γ (kg/m^3), of explosive component of mixture [22]

Fig. 9: High-speed automatic explosion chamber of the A. A. Skochinsky Institute of Mining for spark-safety testing of electric circuits

Fig. 10: Circuit diagram of spark-forming mechanism of explosion chamber of MakNII for spark-safety tests.

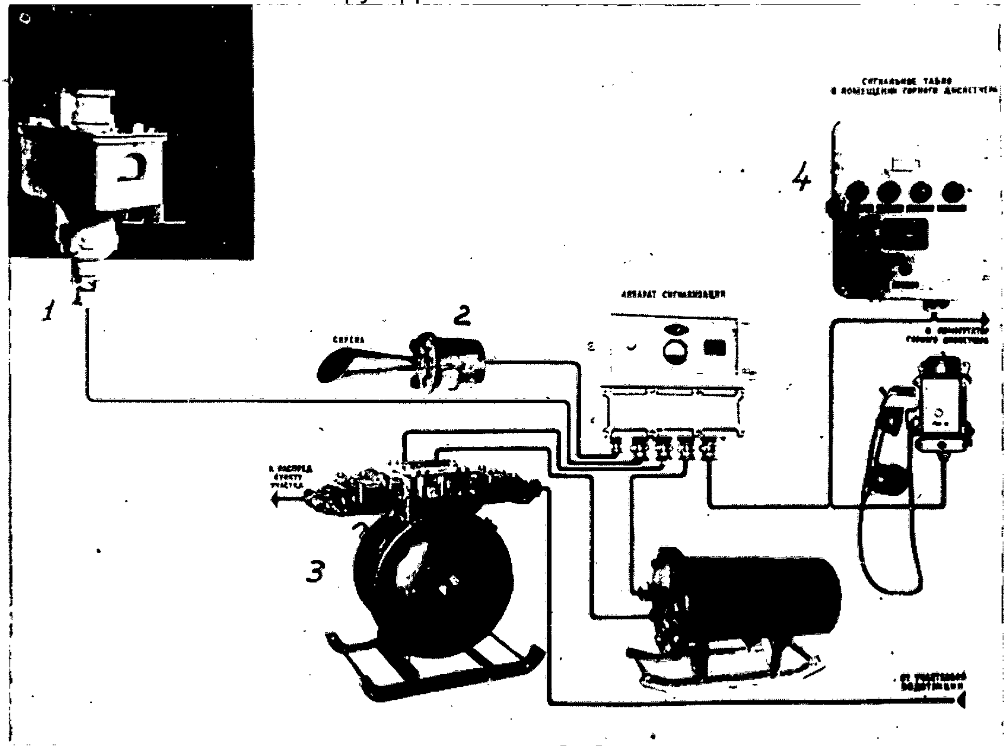

Fig.1.a.

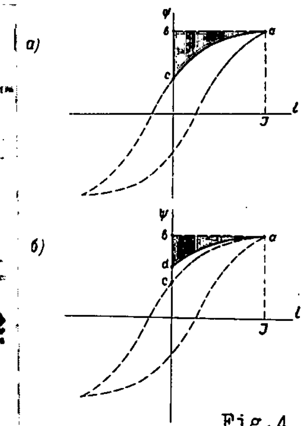

Fig.4

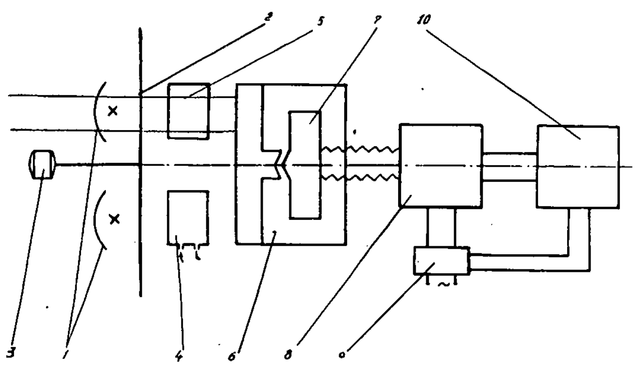

Fig.2

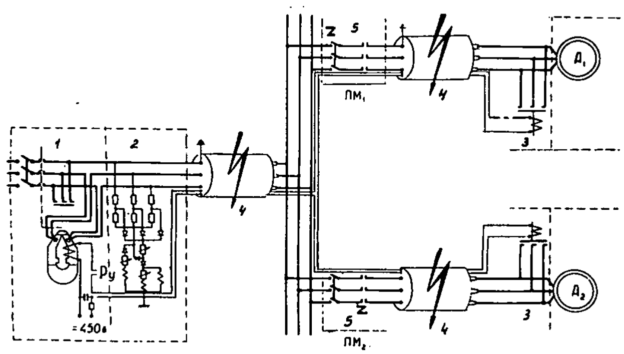

Fig.3

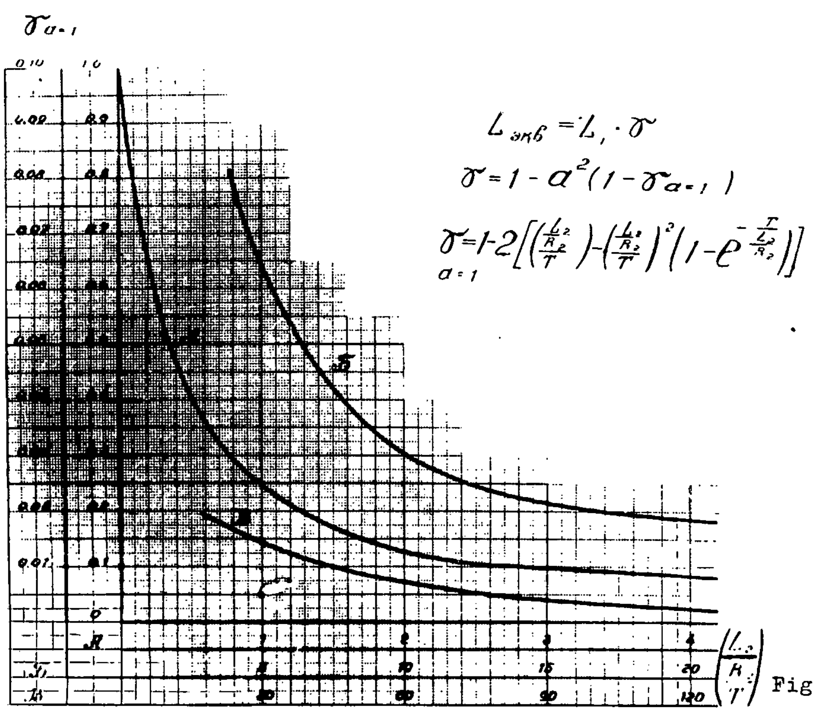

Fig.5

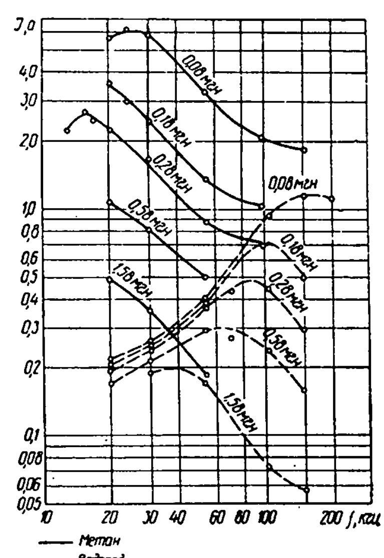

Fig.7

Krawtschenko

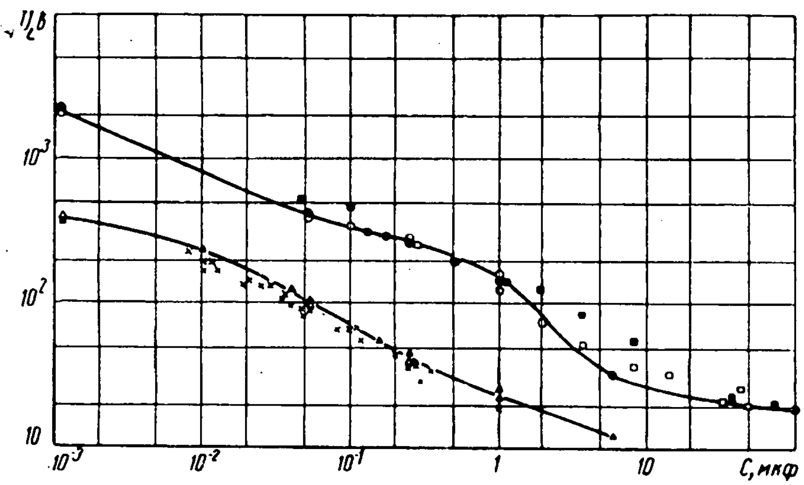

Fig.6

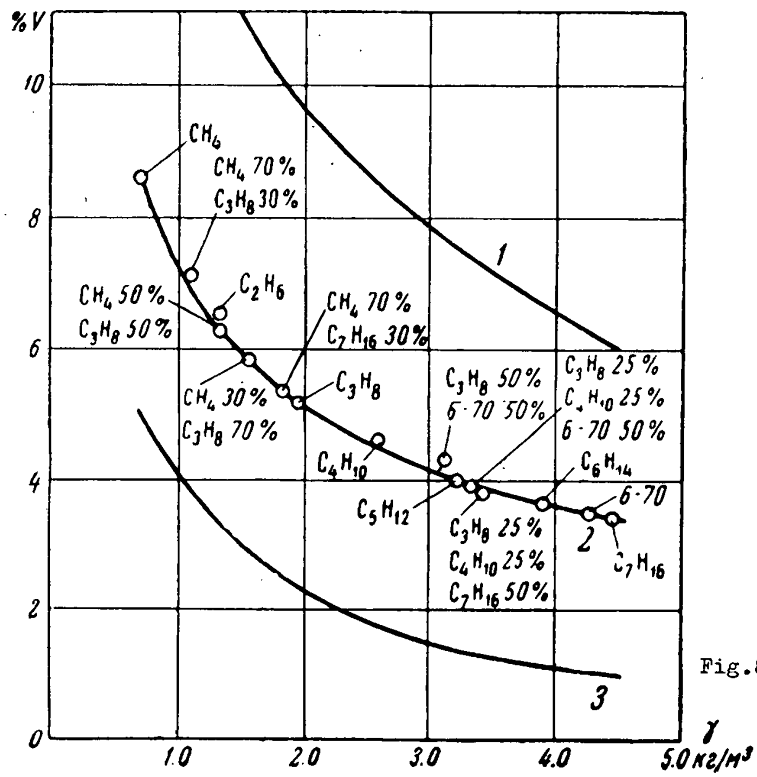

Fig.8

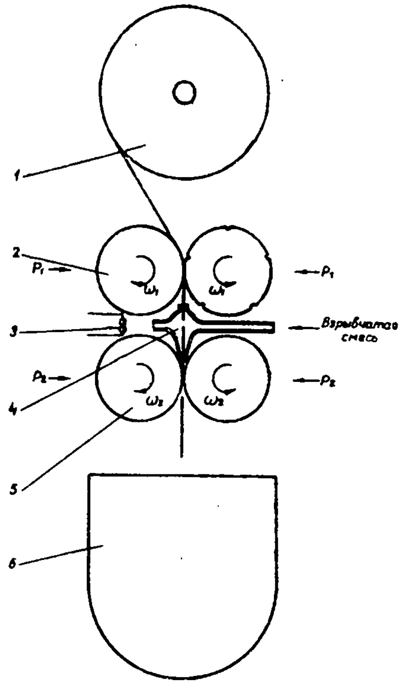

Fig.10

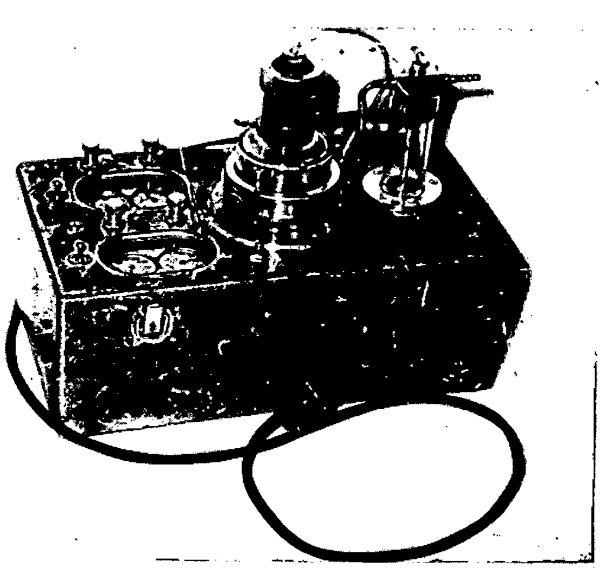

Fig.9

Krawtschenko